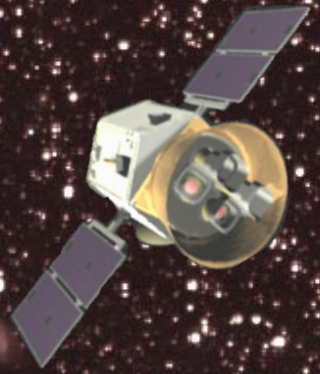
https://ntrs.nasa.gov/search.jsp?R=20180000903 2019-07-26T01:10:44+00:00Z

Prospecting for Habitable Worlds



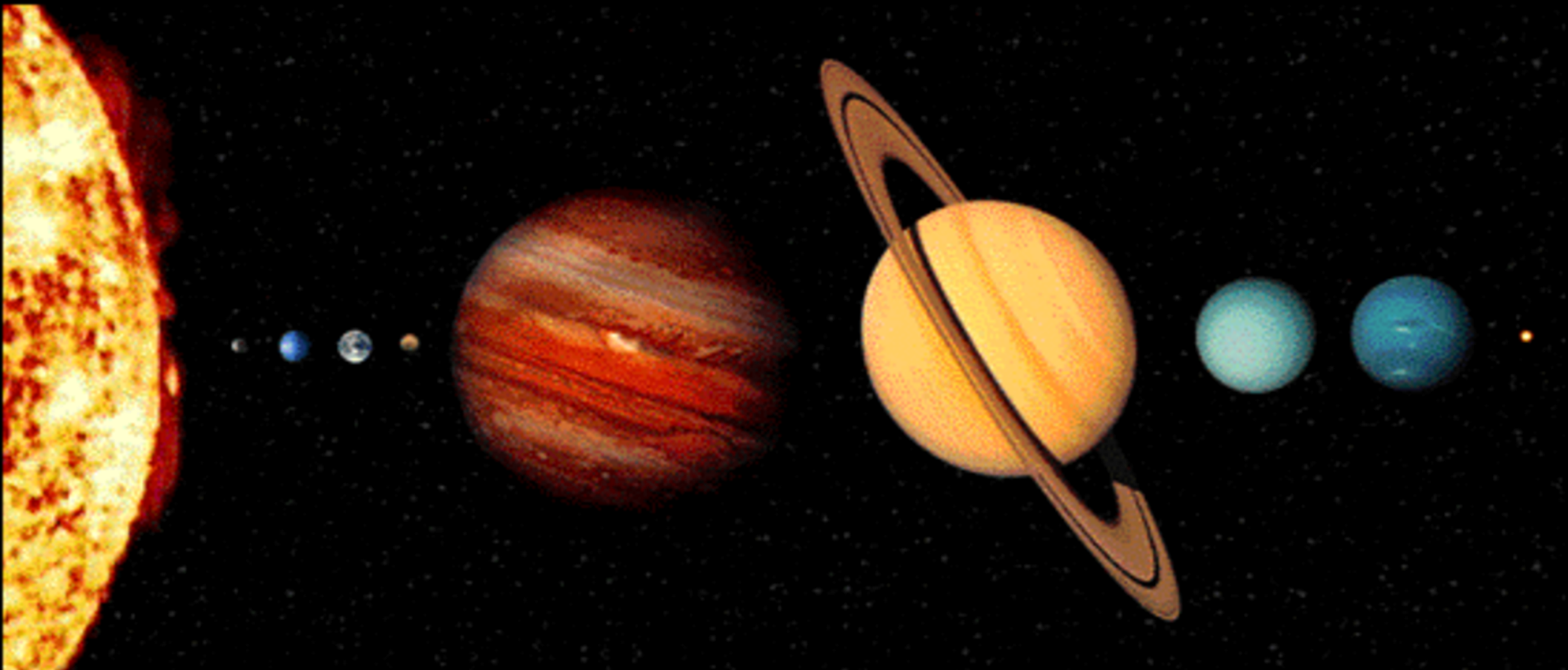
Jon M. Jenkins
NASA Ames Research Center

Thursday October 19, 2017

Symposium on Space Innovations 2017
Atlanta, GA

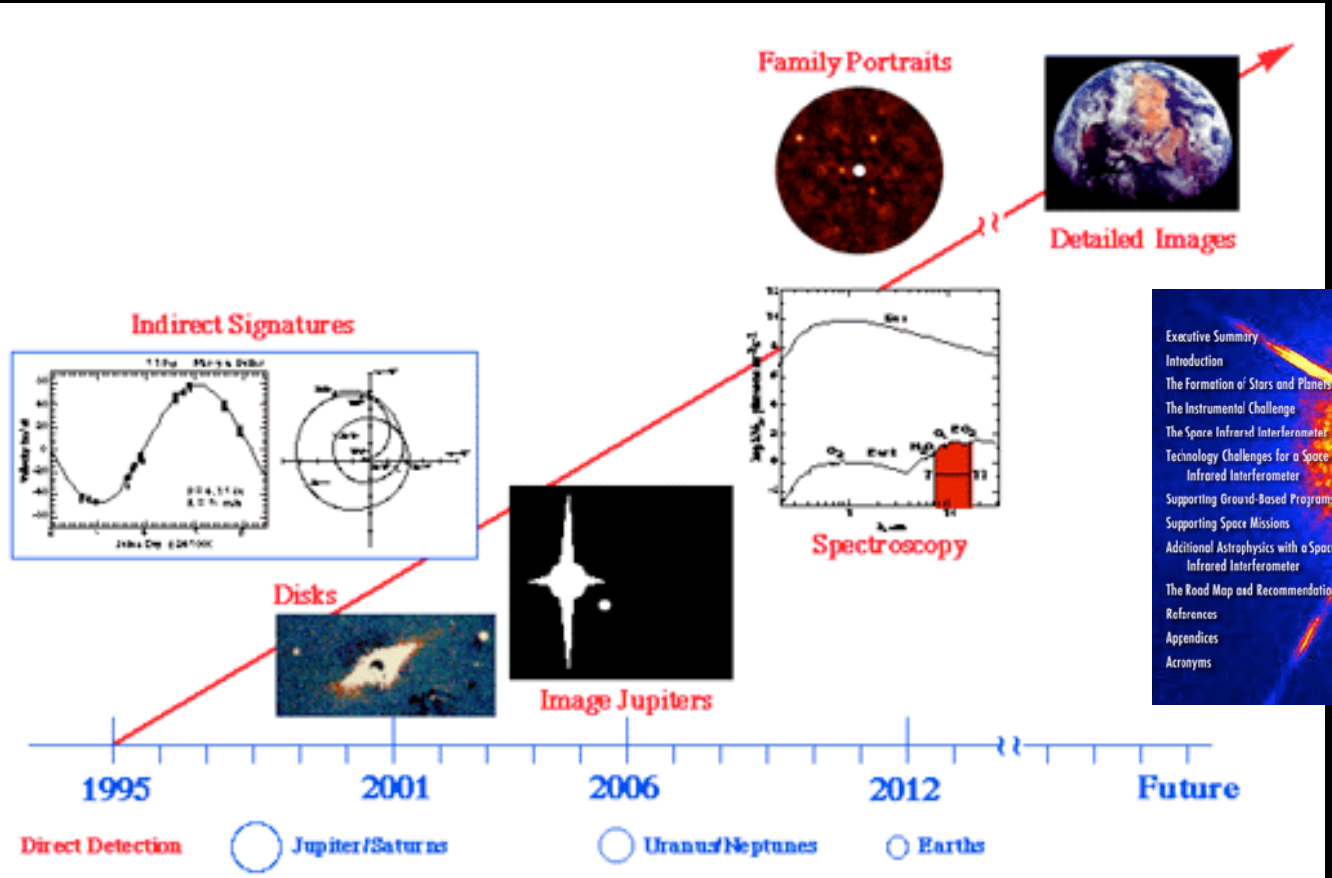
All the Known Planets In 1994

Kepler
A Search for Earth-size Planets

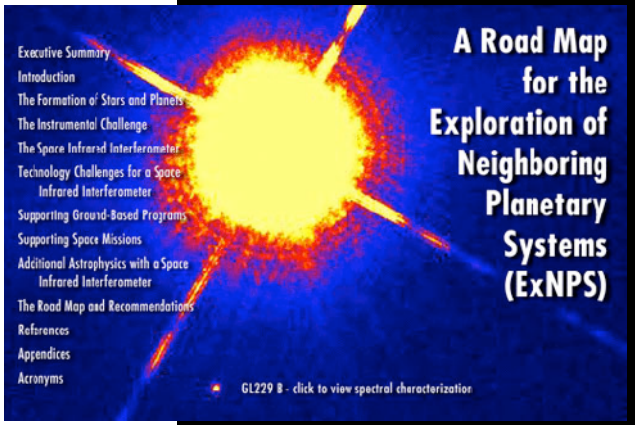


NASA's 1995 ExNPS Report

Kepler
A Search for Earth-size Planets

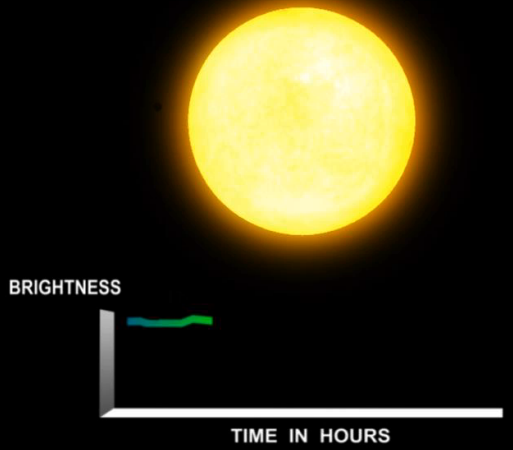


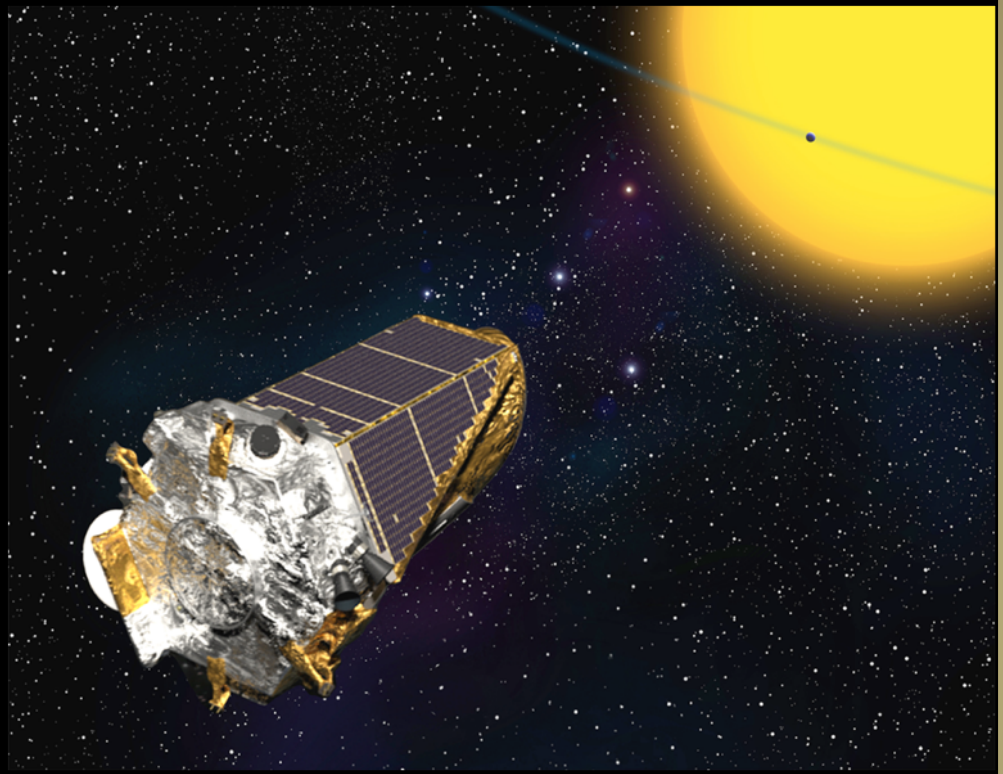
Transit Photometry not Recommended!



The *Kepler* Mission

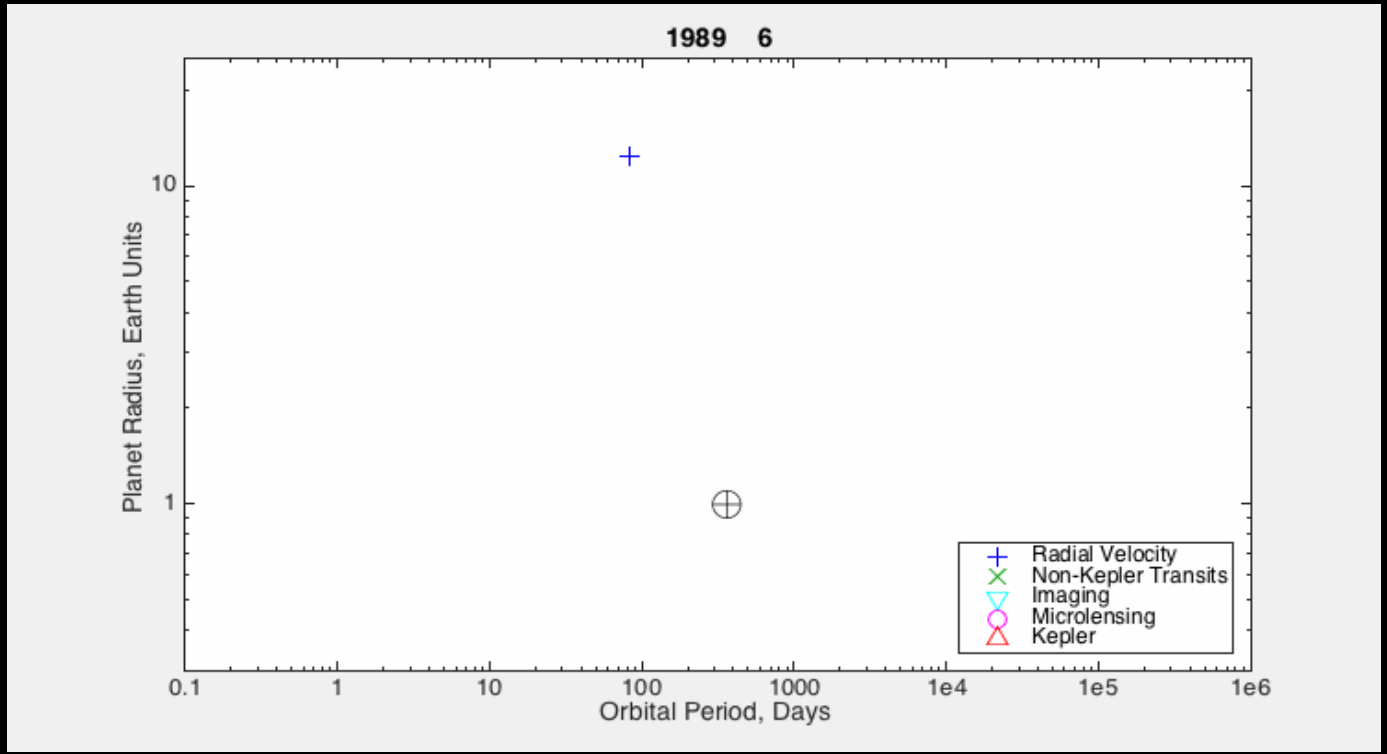
What fraction of sun-like stars in our galaxy host potentially habitable Earth-size planets?





Exoplanet Discoveries Over Time*

Kepler
A Search for Earth-size Planets



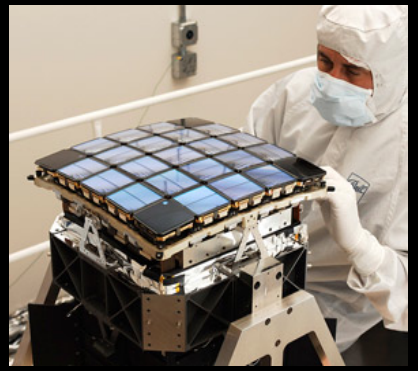
Radii estimated for non-transiting exoplanets
Discovery data dithered slightly

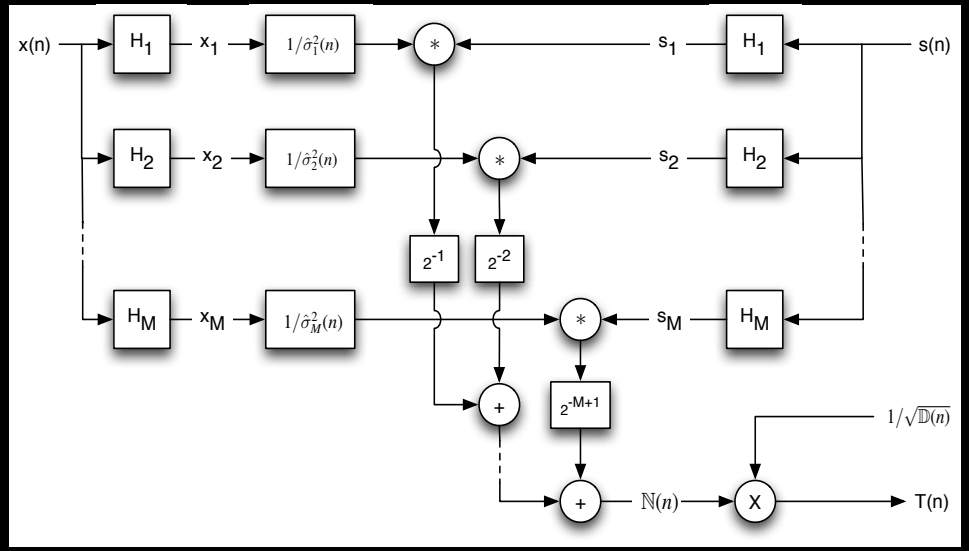
*According to https://exoplanetarchive.ipac.caltech.edu as of 8/29/17

Enabling *Kepler*

Kepler
A Search for Earth-size Planets

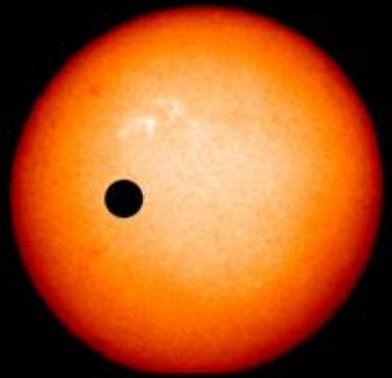
- Back illuminated CCDs (20 ppm photometric precision)
- Sophisticated algorithms
- Computational infrastructure



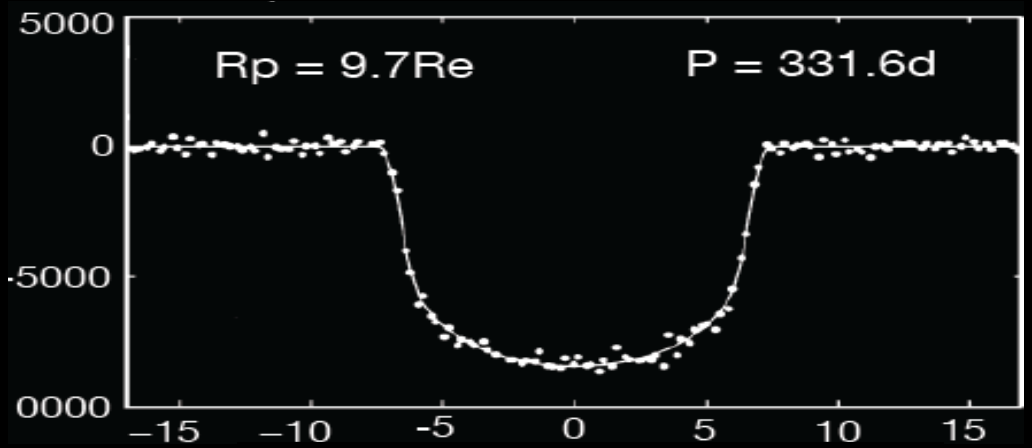


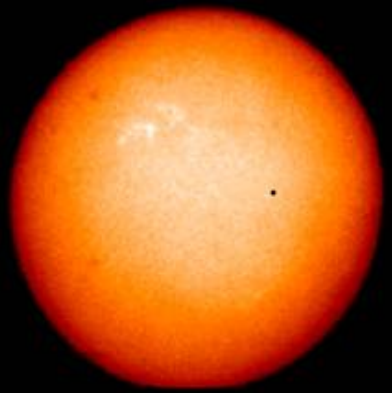
How Hard is it to Find Good Planets?

Kepler
A Search for Earth-size Planets

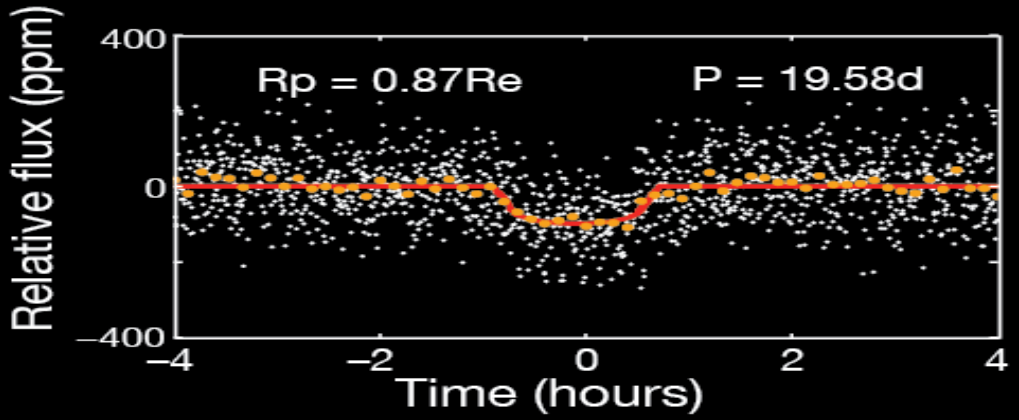


Jupiter (~1%)

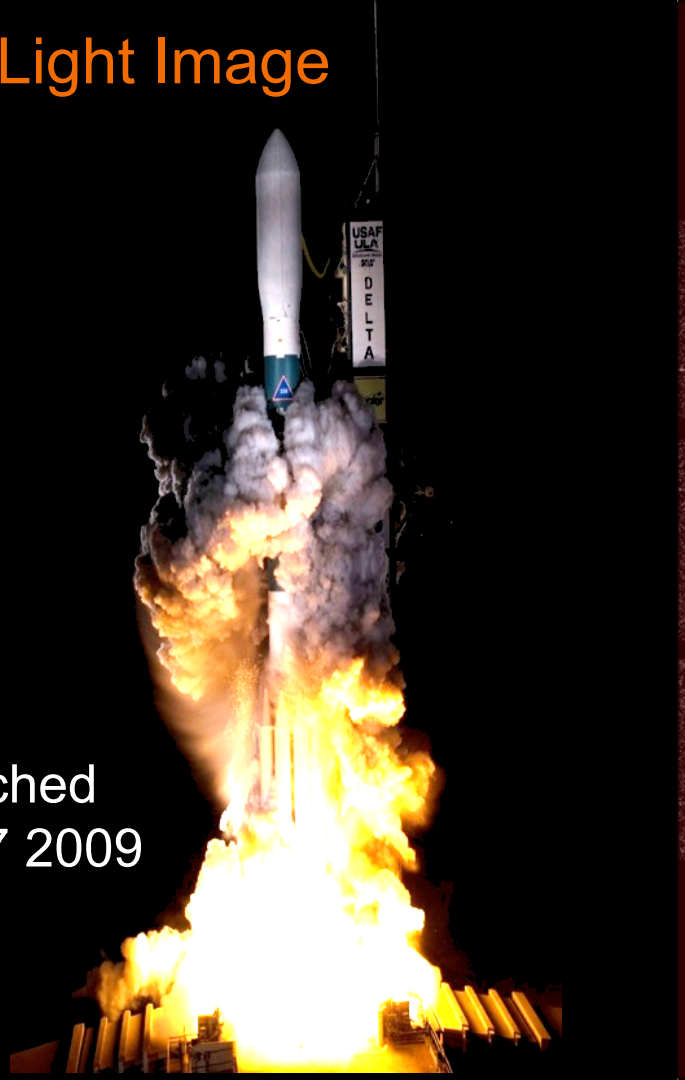




Earth (~0.01%)



First Light Image

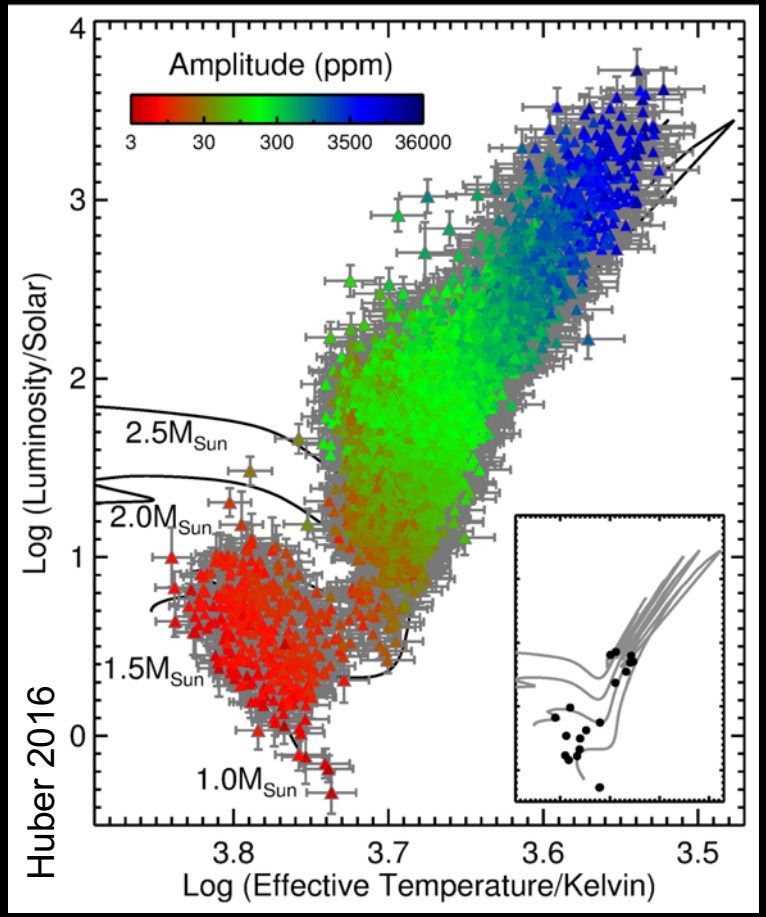


Launched
March 7 2009

First Light Image

Launched
March 7 2009

Asteroseismology with Kepler

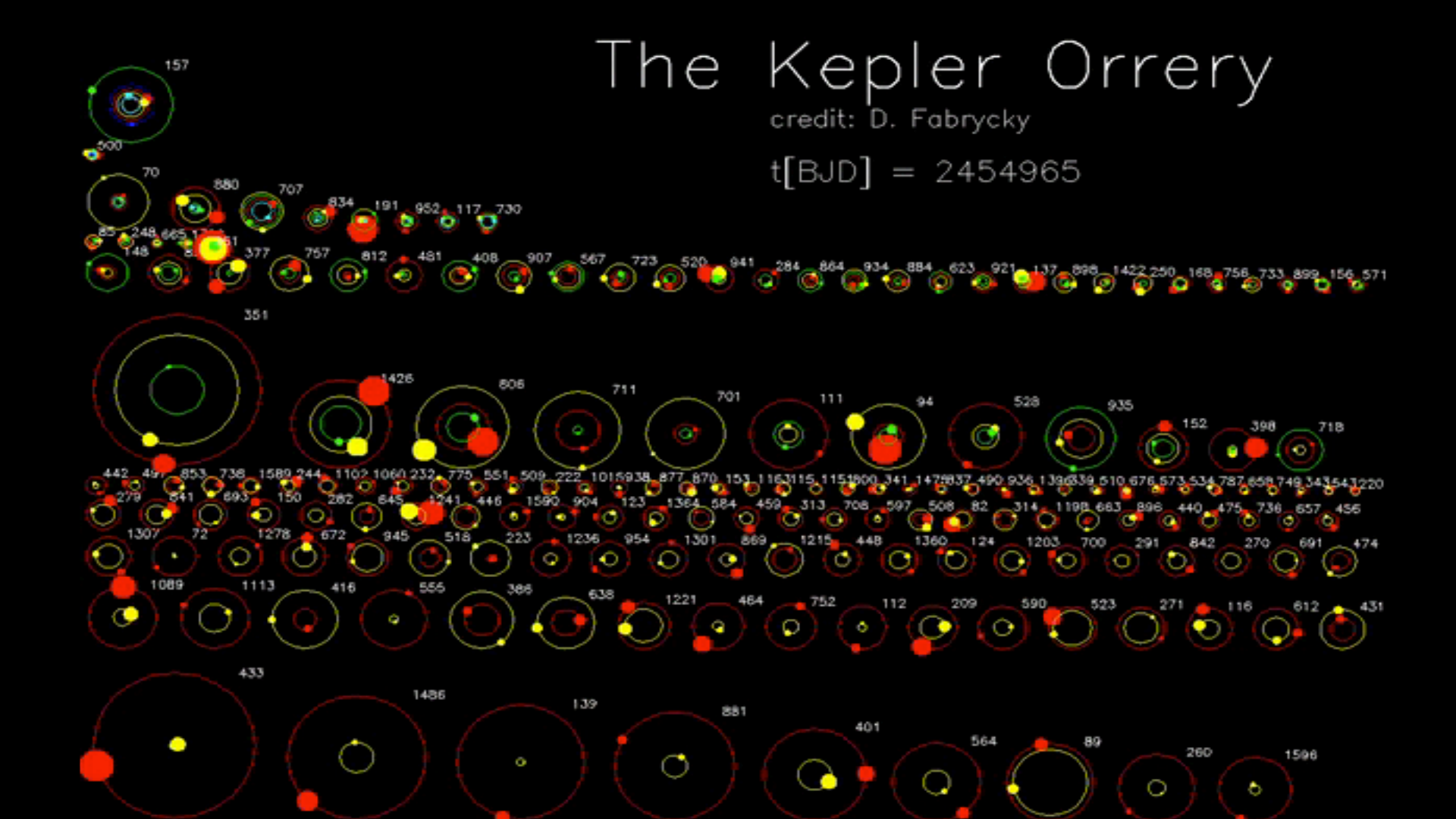


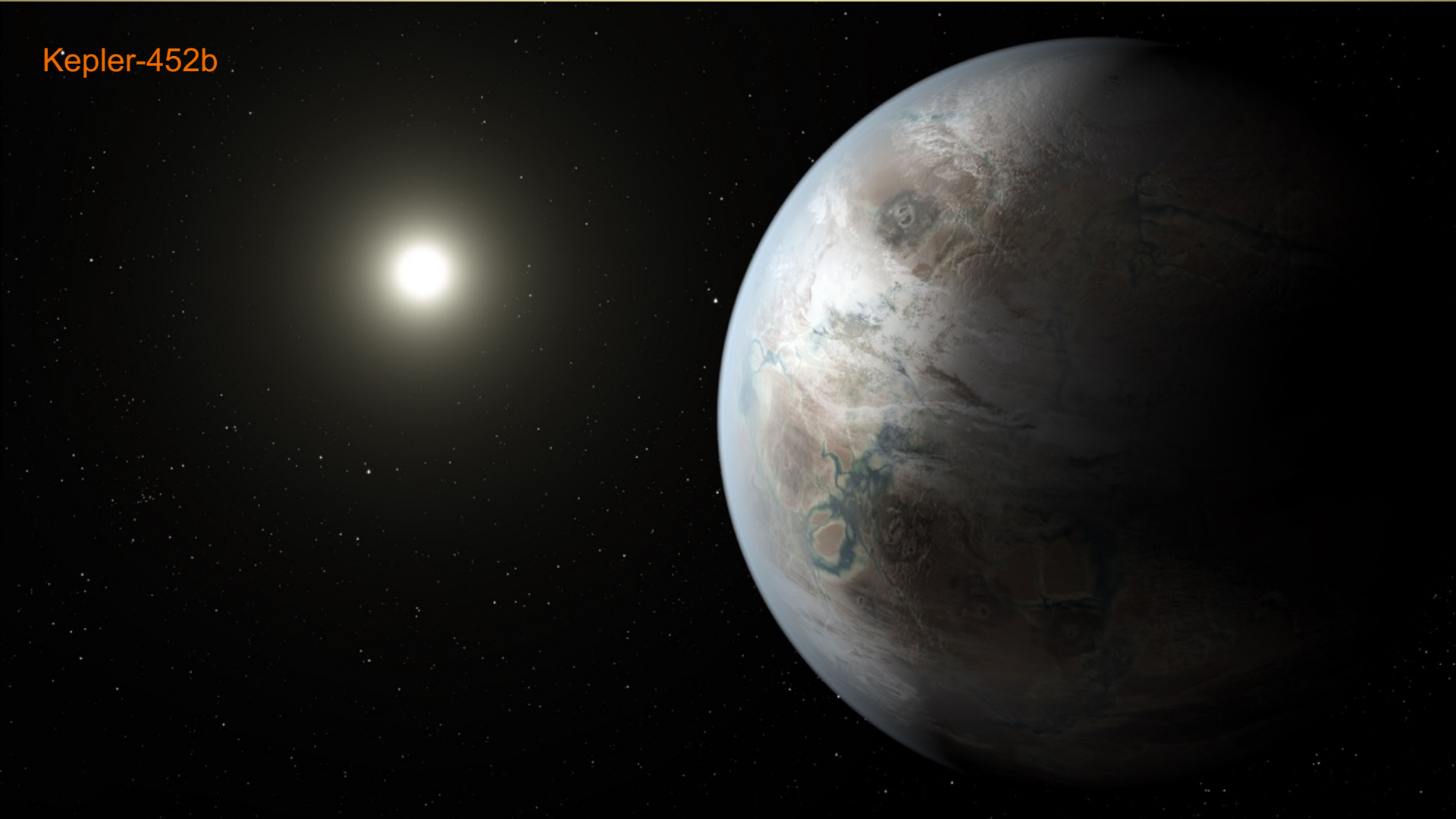
Inset – Stellar oscillation Detections before Kepler.

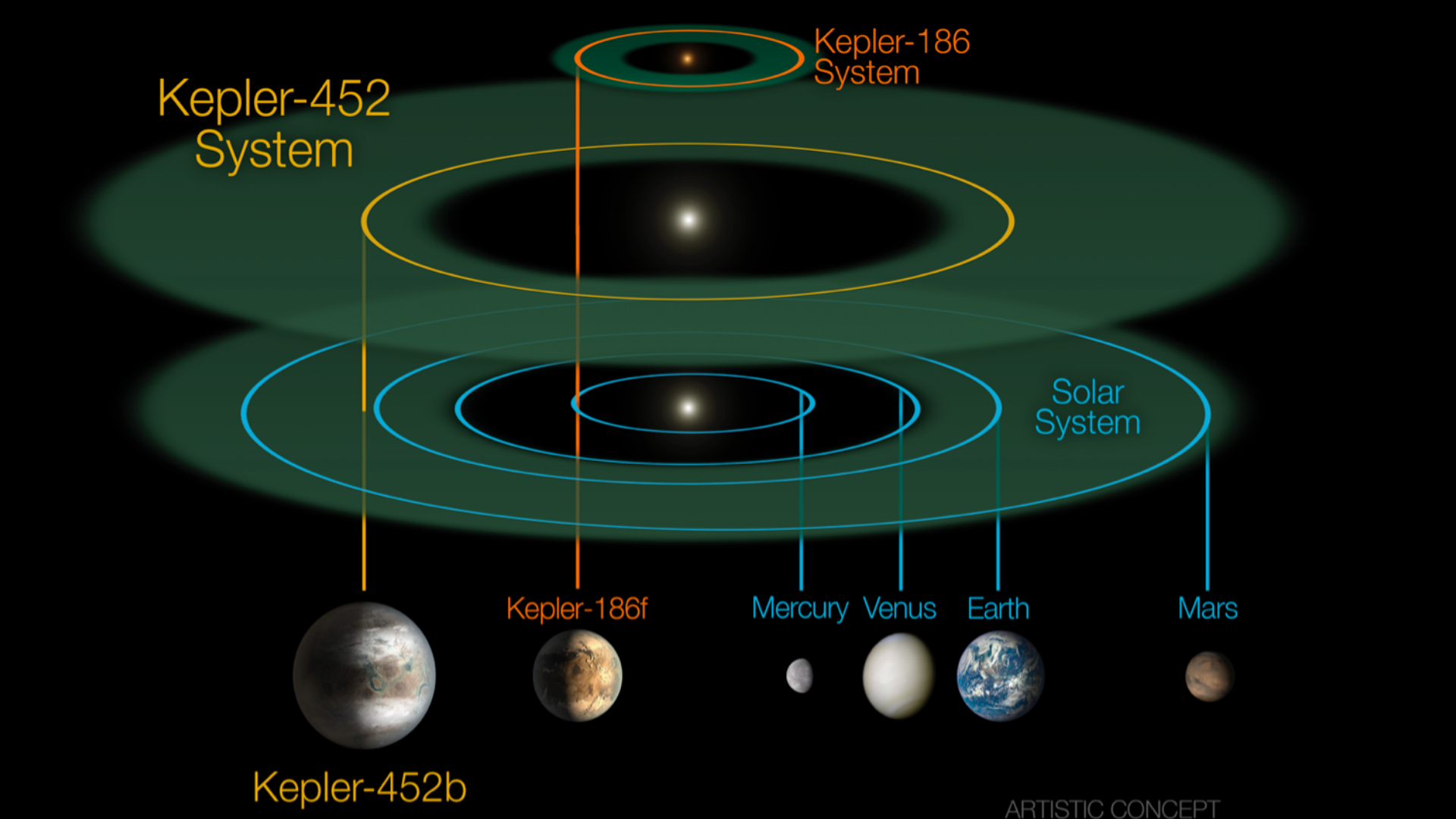
Main: Kepler's 4 years of study show the stars amplitudes (ppm) as color coded points. Extended study provides –

- Stellar ages and radii
- Internal differential rotation
- Convection zone depths ages
- Rotation axis orientation
- Heliophysics-like results

…for 15000+ stars

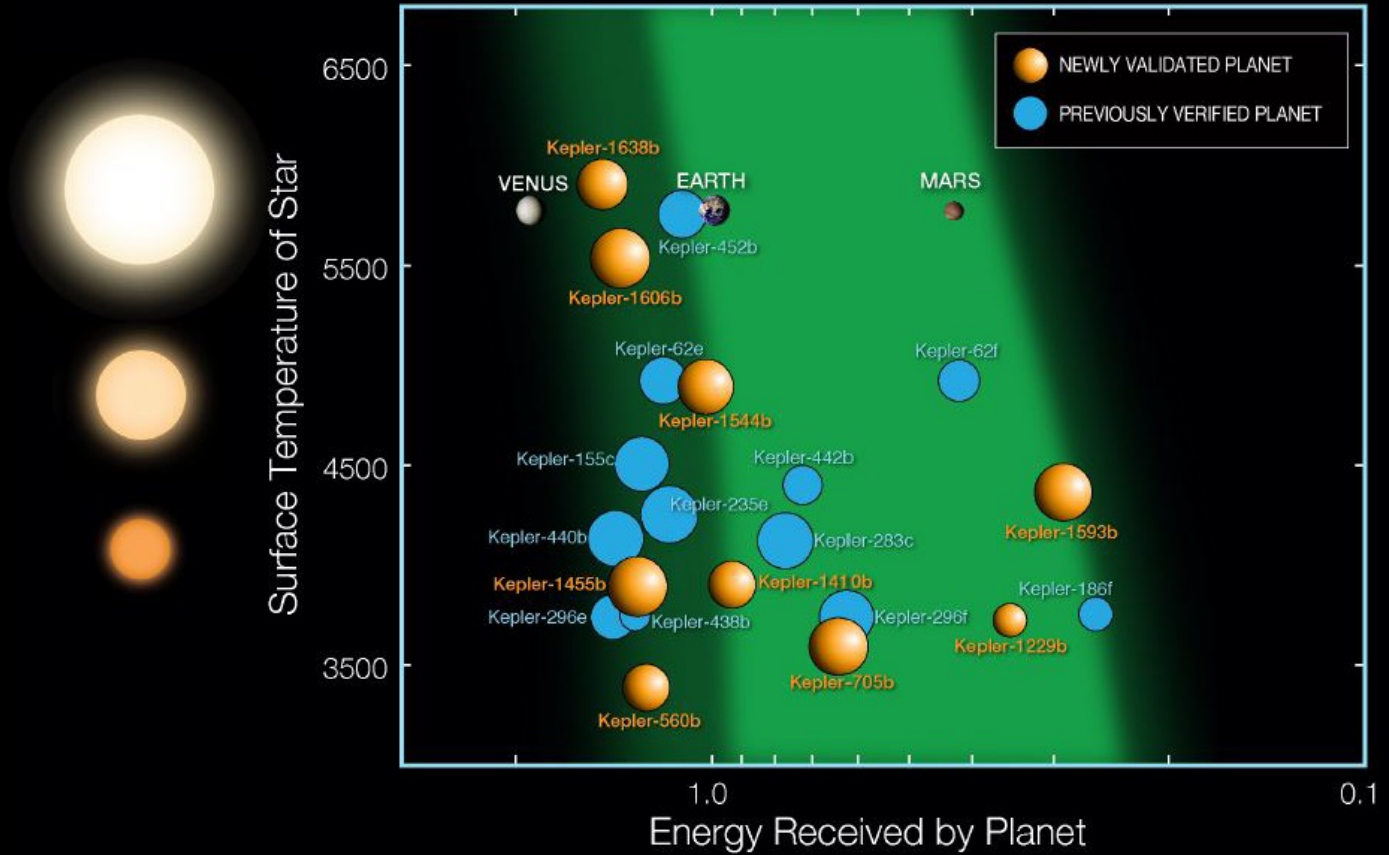

The Kepler Orrery
credit: D. Fabrycky
t[BJD] = 2454965


Kepler-452b

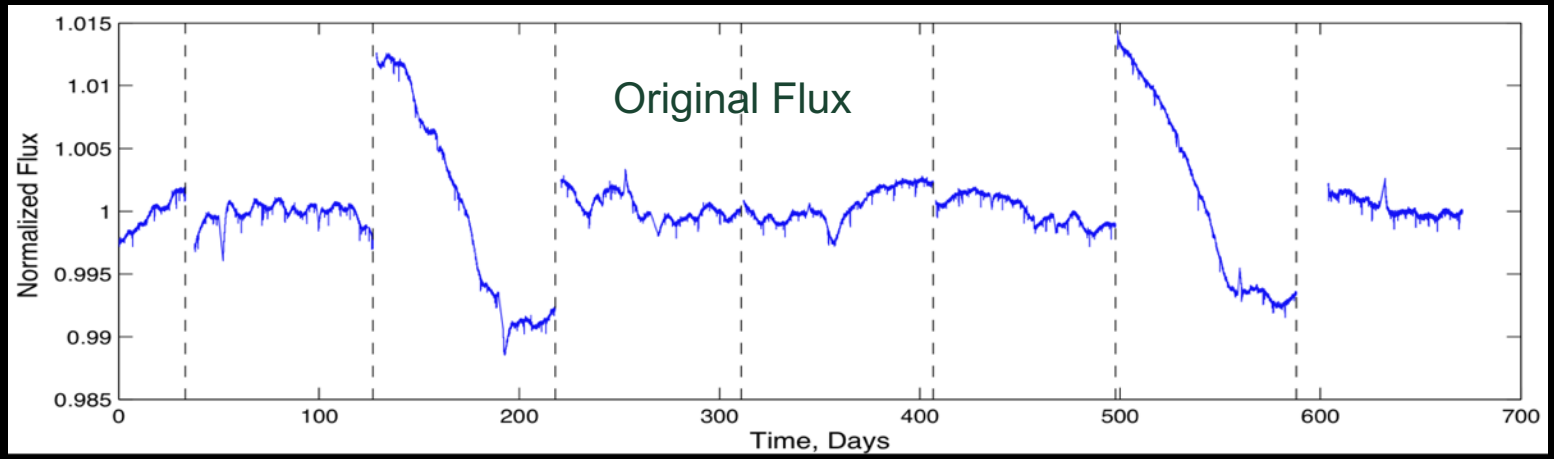

Kepler-186
System
Kepler-452
System
Solar
System
Kepler-186f
Mercury
Venus
Earth
Mars
Kepler-452b
ARTISTIC CONCEPT

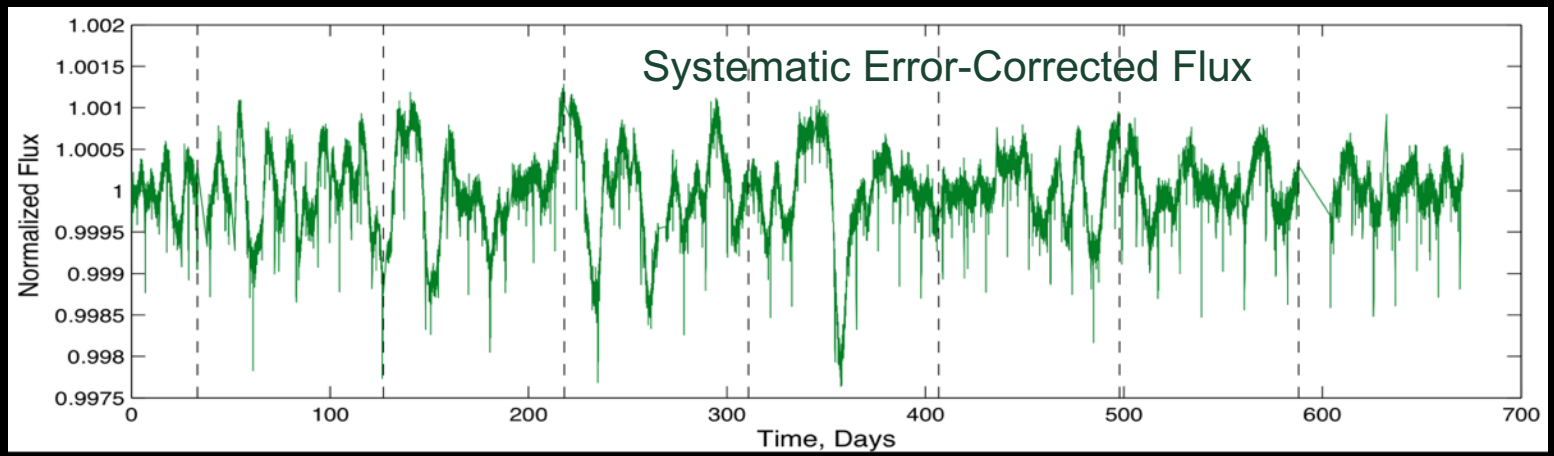
Kepler's Small Habitable Zone Planets

As of May 10, 2016



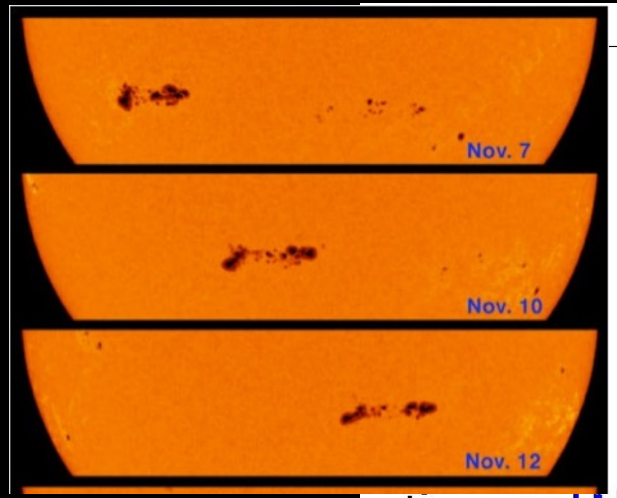
Correcting Systematic Errors

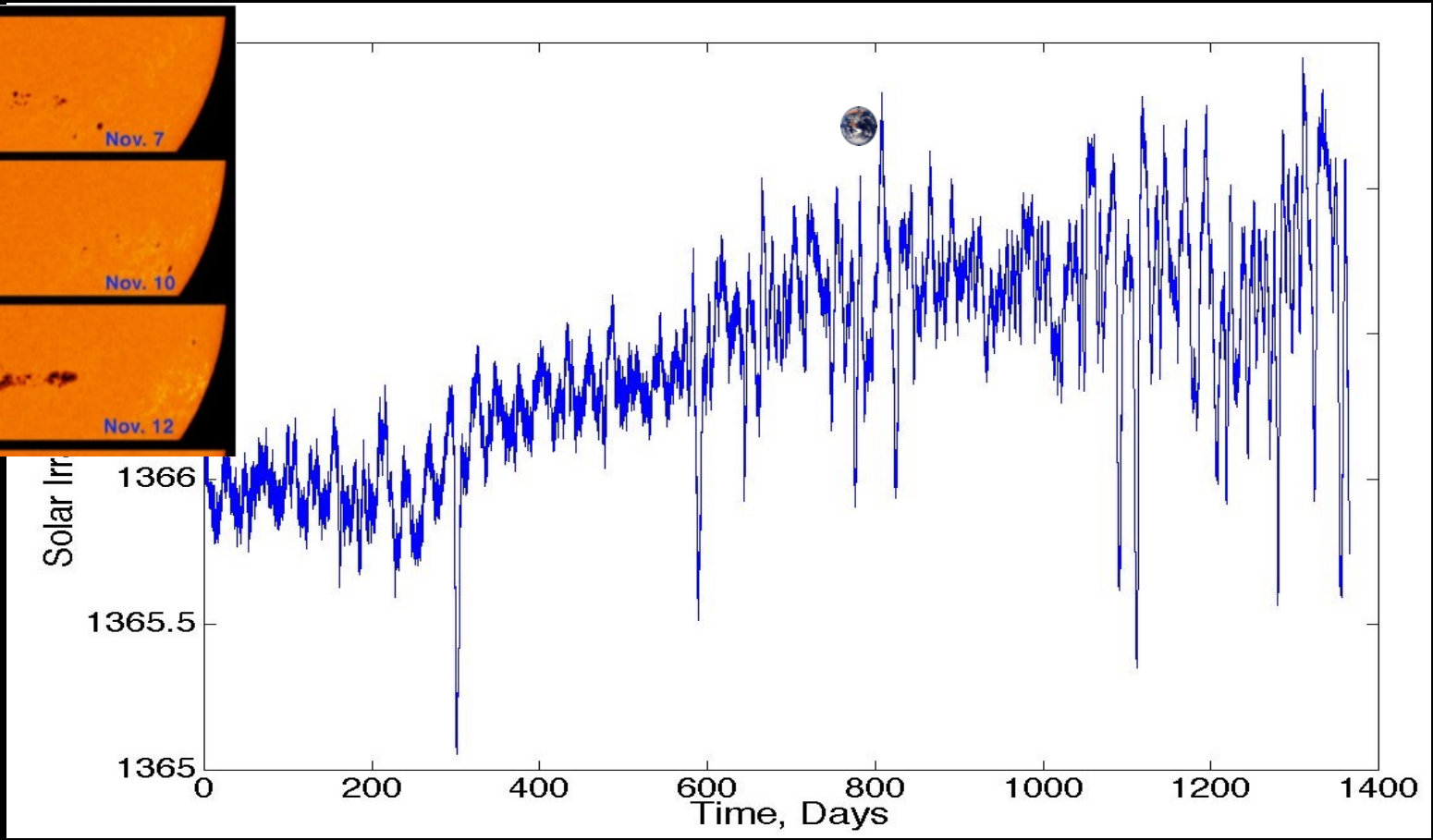




The Search Problem

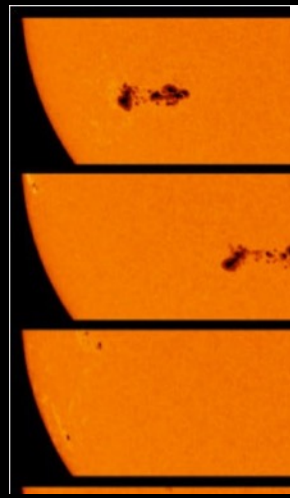
Solar Variability

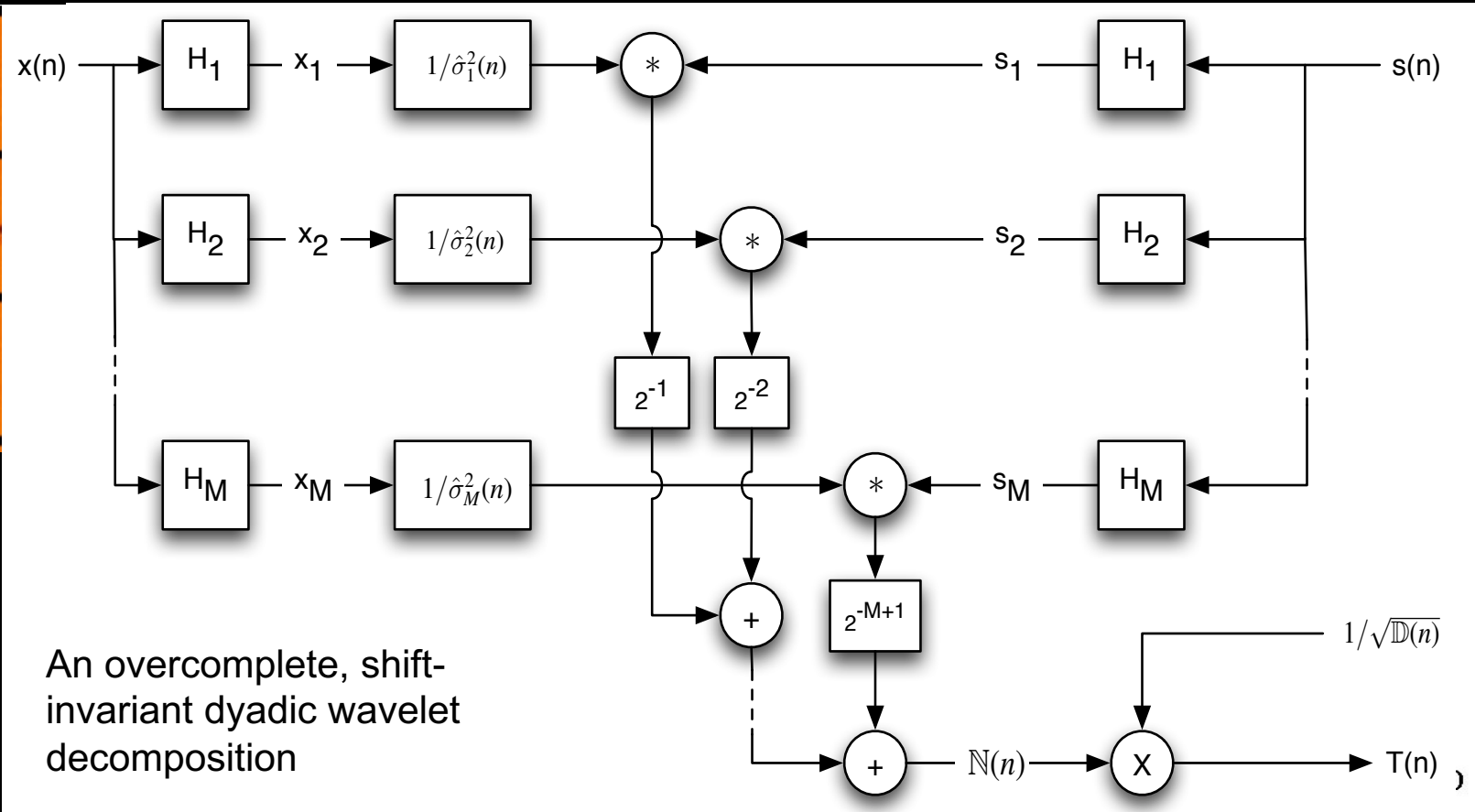




Sophisticated Signal Processing Algorithms

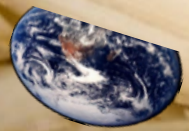
Kepler
A Search for Earth-size Planets



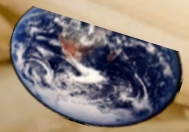


An overcomplete, shift-invariant dyadic wavelet decomposition

The Search Problem



The Search Problem



Keeping Up with the Data

Hardware Architecture:
Kepler Science Operations Center

Kepler
A Search for Earth-size Planets

64 hosts, 712 CPUs,

3.7 TB of RAM,

148 TB of raw disk storage

Hardware Architecture: NAS Pleiades Supercomputer

Kepler
A Search for Earth-size Planets

7.25 Pflop/s peak cluster

246,048 cores

938 TB of memory

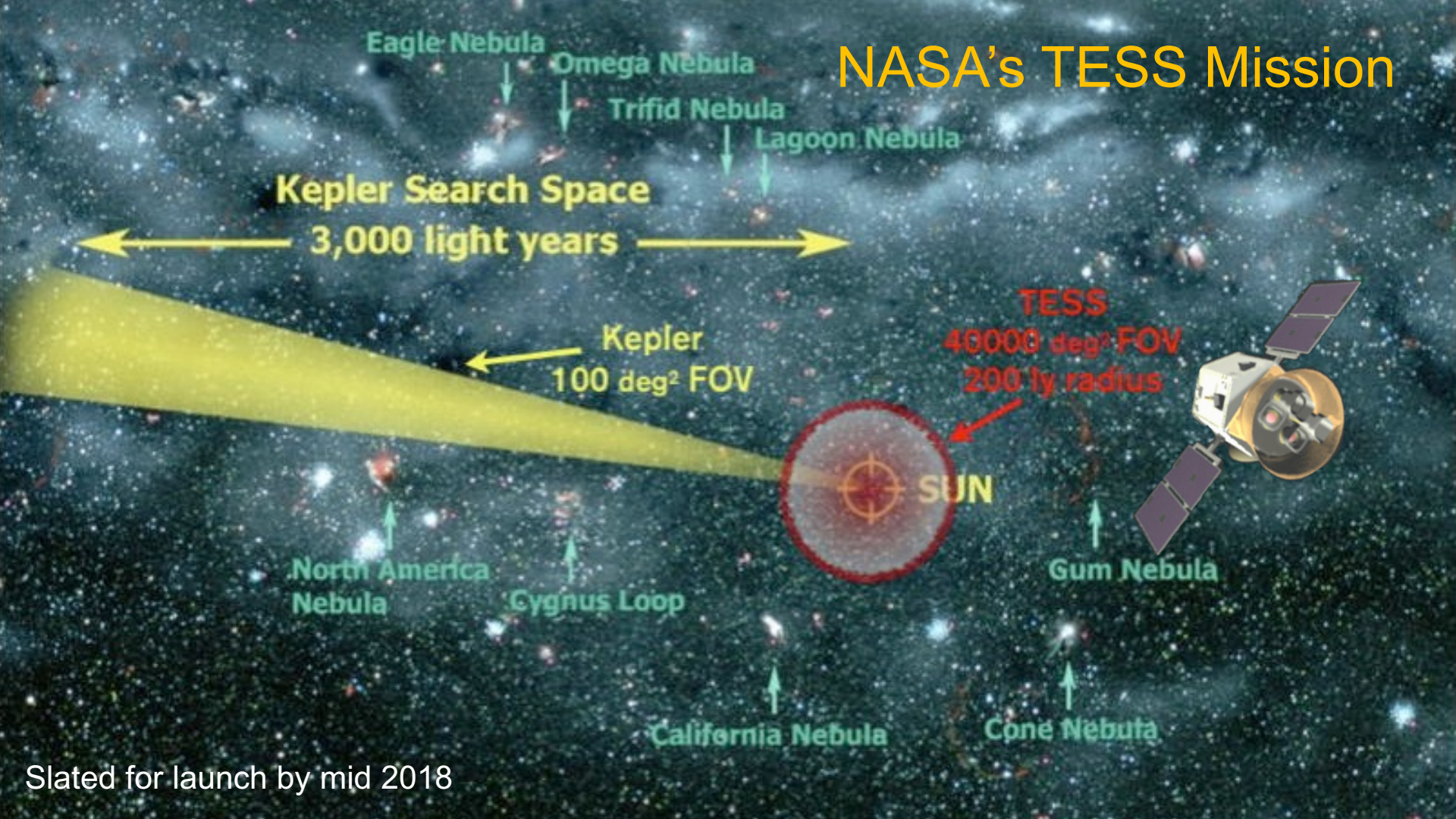
15 PB of storage

Kepler taught us that planets are ubiquitous:

What Next?

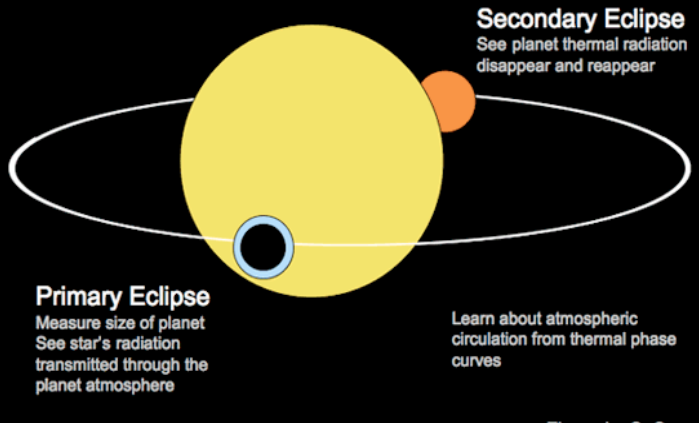
The View from Proxima b
NASA/JPL

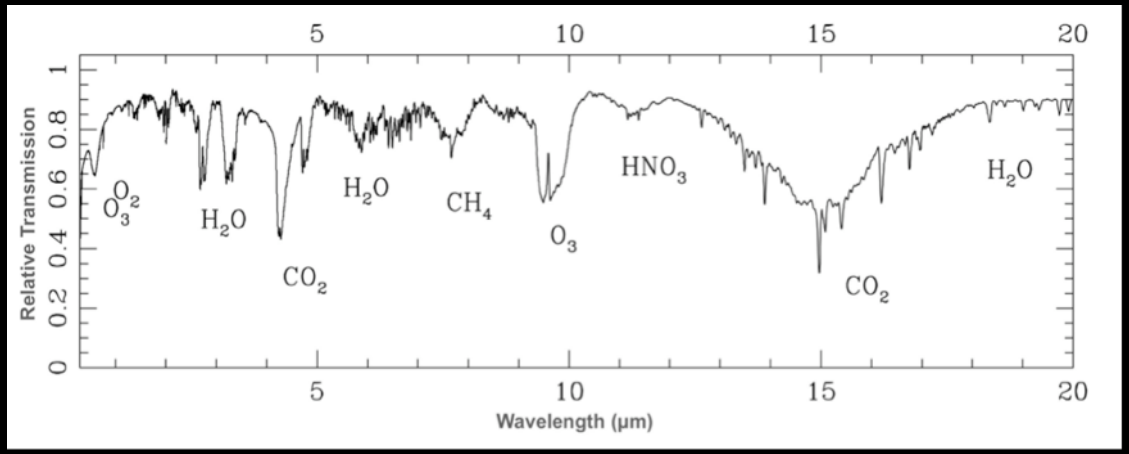
NASA's TESS Mission



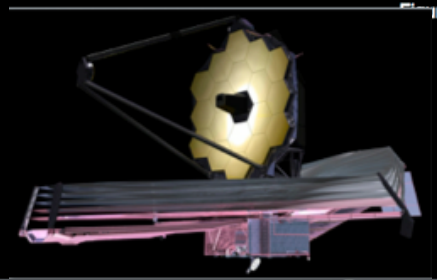
Slated for launch by mid 2018

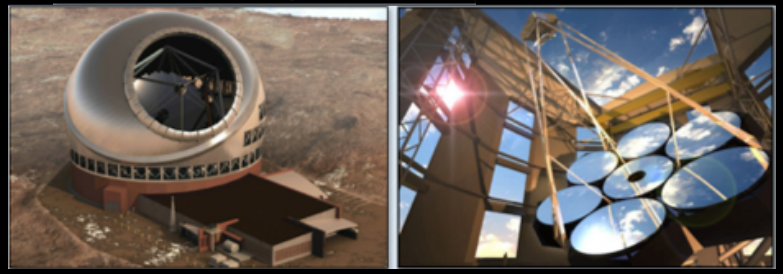
Detecting Biomarkers through Transit Spectroscopy





Kaltenegger, L. and Traub, W. (2009) Transits of Earth-Like Planets, ApJ





Transiting planets provide opportunities to determine the bulk planetary density and to characterize their atmospheres

Exoplanet Missions

NASA

JWST

WFIRST-AFTA

TESS

Kepler

New Worlds Telescope

Spitzer

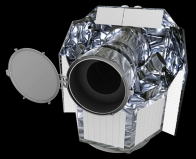
Hubble

Ground-based Observatories

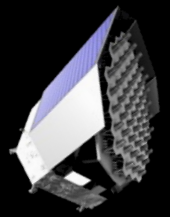
2001 Decadal Survey

2010 Decadal Survey

+ ESA's CHEOPS (2018)



ESA - C. Carreau



+ ESA's PLATO Mission (2026)